Title: Rethinking the origin of neutrino masses: the role of gravity

Speakers: Lena Funcke

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Rethinking the origin of neutrino masses: the role of gravity

Lena Funcke

in collaboration with Gia Dvali *et al.*

(1602.03191, 1608.08969, 1811.01991, 1905.01264)

Simplicity III, Perimeter Institute, 9 September 2019

Question: Origin of Small Neutrino Masses?

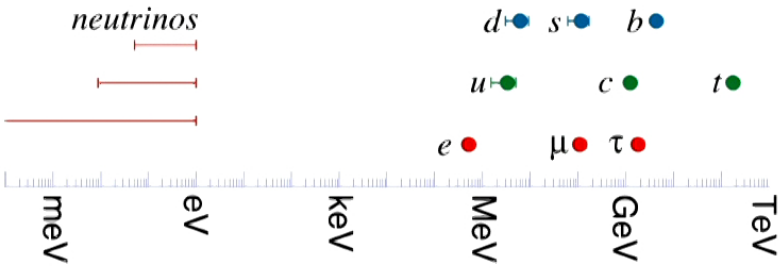

Image credits: IKEA and Murayama (2018).

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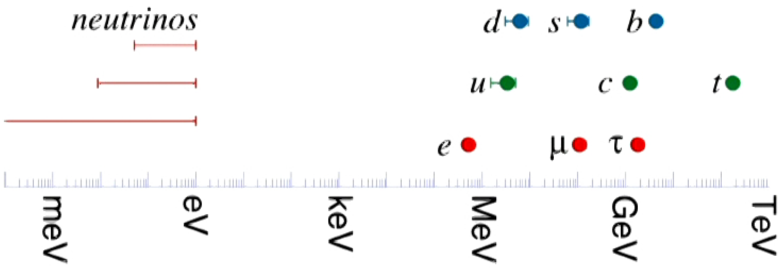
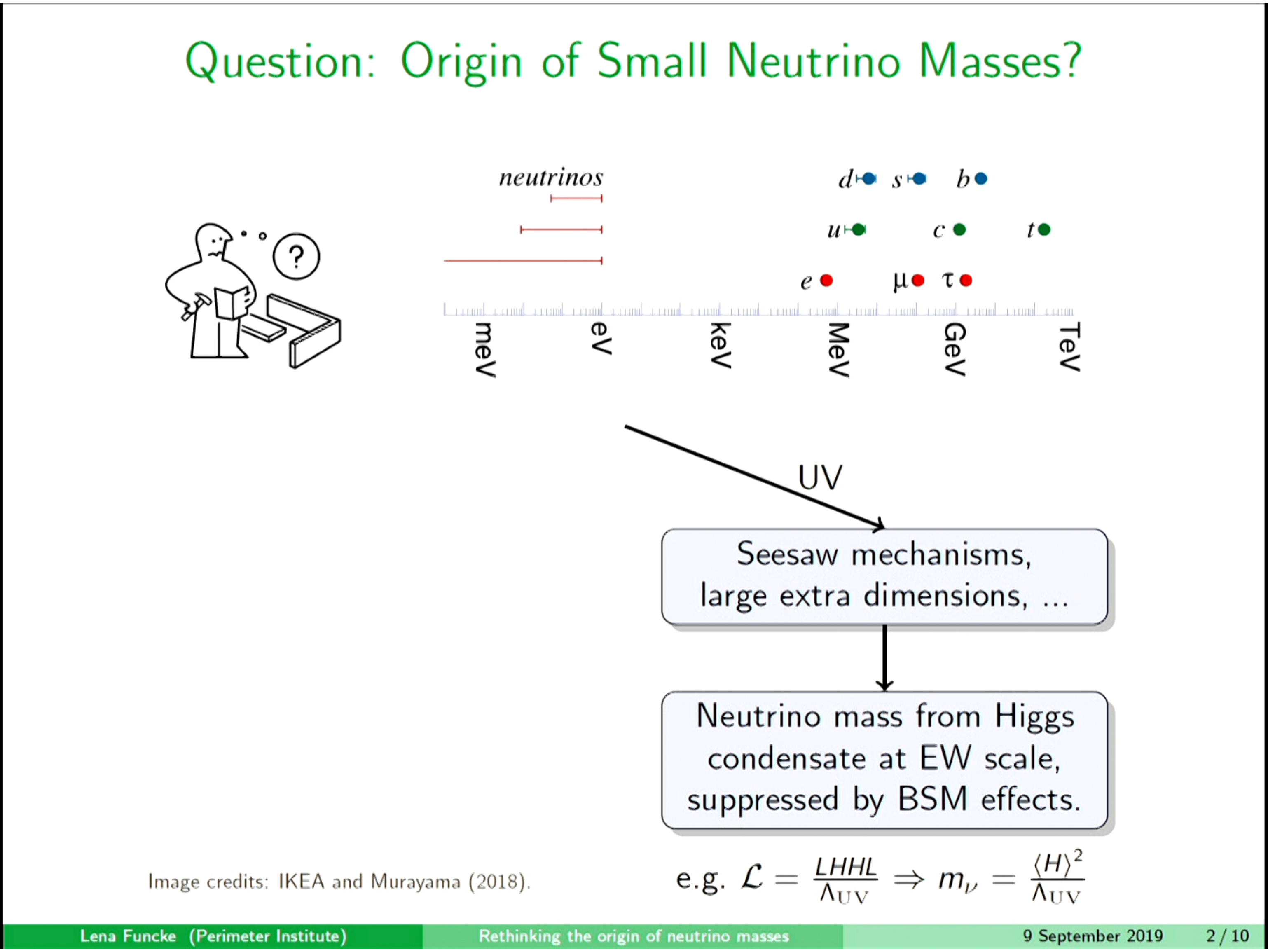


UV

Seesaw mechanisms,
large extra dimensions, ...

Image credits: IKEA and Murayama (2018).



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Neutrino mass from Higgs condensate at EW scale, suppressed by BSM effects.

Image credits: IKEA and Murayama (2018).

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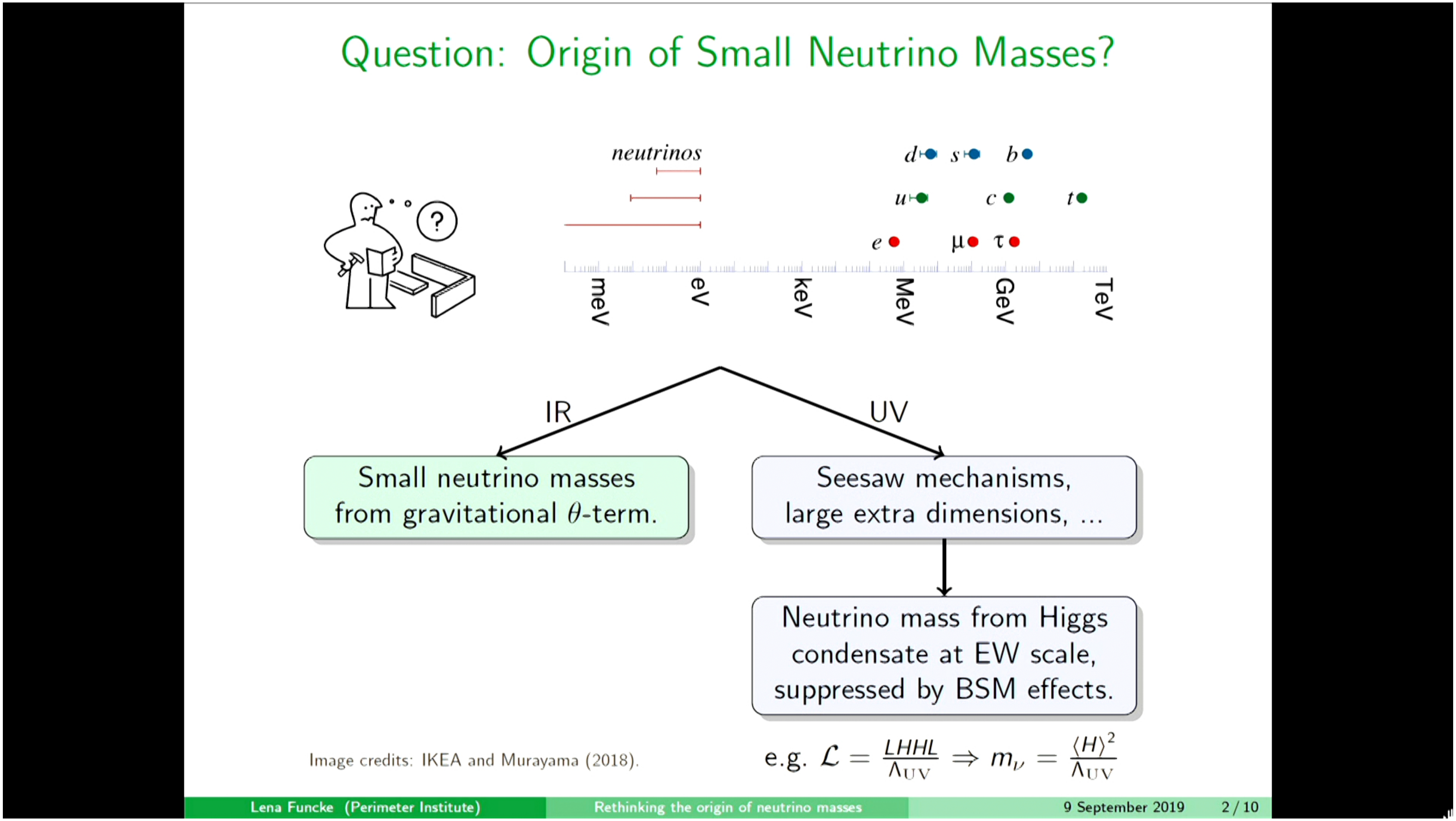

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Small neutrino masses from gravitational θ-term.

Seesaw mechanisms, large extra dimensions, ...

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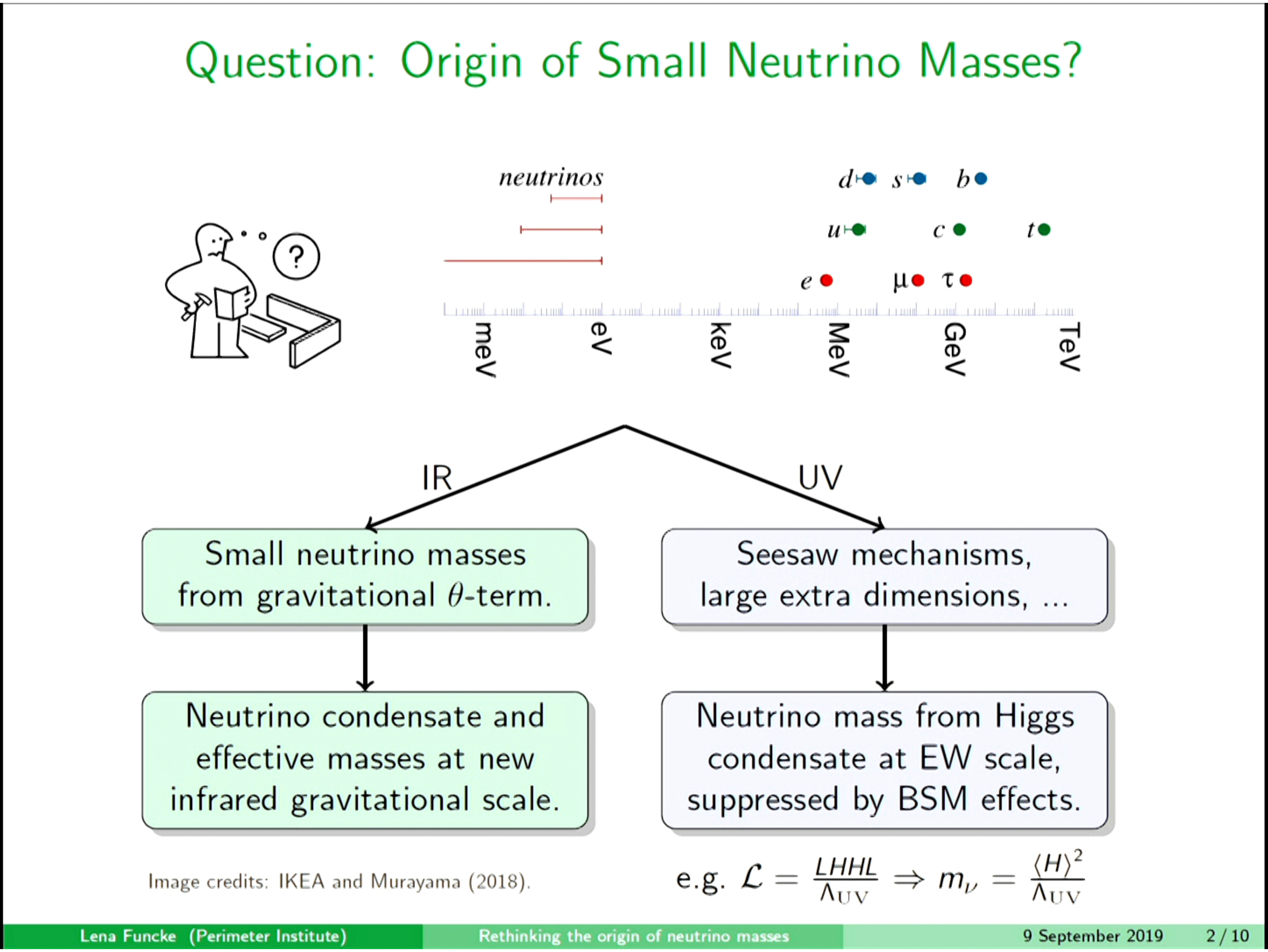

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Neutrino condensate and effective masses at new infrared gravitational scale.

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Analogy: Non-Perturbative QCD Vacuum

- QCD: θ-term $\mathcal{L}_{\mathrm{QCD}} \supset \theta G\tilde{G}$ is made physical by non-perturbative effects [1].

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Chiral $U(1)_A$ anomaly	$\partial_\mu j_5^\mu = G\tilde{G} + m_q \bar{q}\gamma_5 q$	[4]

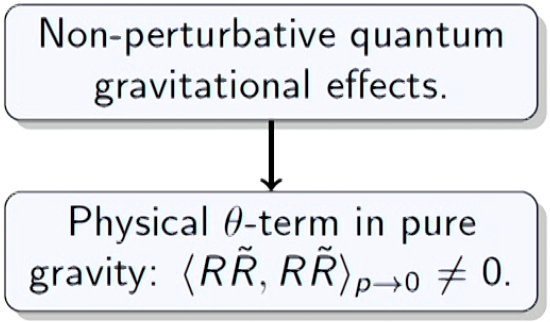
[1] 't Hooft (1976); Witten (1979); Veneziano (1979).

[4] Adler (1969); Bell, Jackiw (1969).

$$\mathcal{L}_{QCD} \supset \theta\, dC\,, \quad C = A\,dA - \frac{3}{2} AAA\,, \quad \langle G\widehat{G}, G\widehat{G}\rangle_{p\to 0} = -m_q \langle \bar{q} q \rangle$$

$$\mathcal{L}_{G} \supset \theta_G\, dC_G\,, \quad C_G = \Gamma\, d\Gamma - \frac{3}{2} \Gamma\Gamma\Gamma\,, \quad \langle R\widehat{R}, R\widehat{R}\rangle_{p\to 0} = -m_\nu \langle \bar{\nu} \nu \rangle$$

The Model: Neutrino Condensation



Non-perturbative quantum gravitational effects.

Physical θ-term in pure gravity: $\langle R\tilde{R}, R\tilde{R}\rangle_{p\to 0} \neq 0$.

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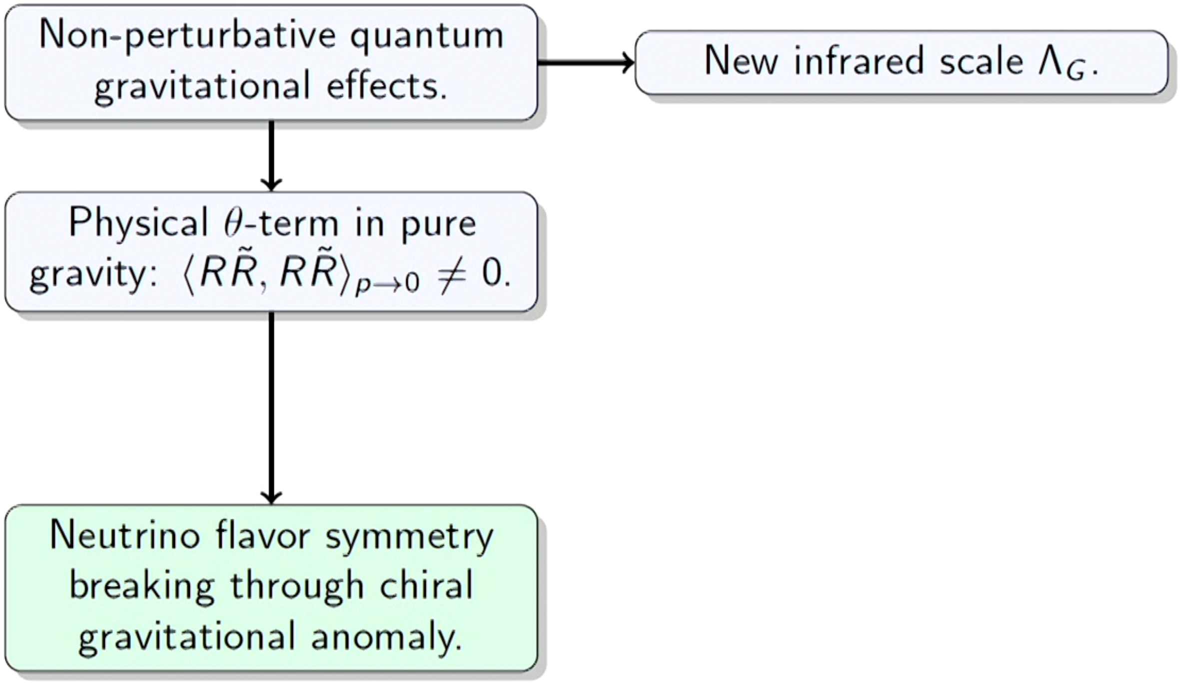

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New infrared scale Λ_G.

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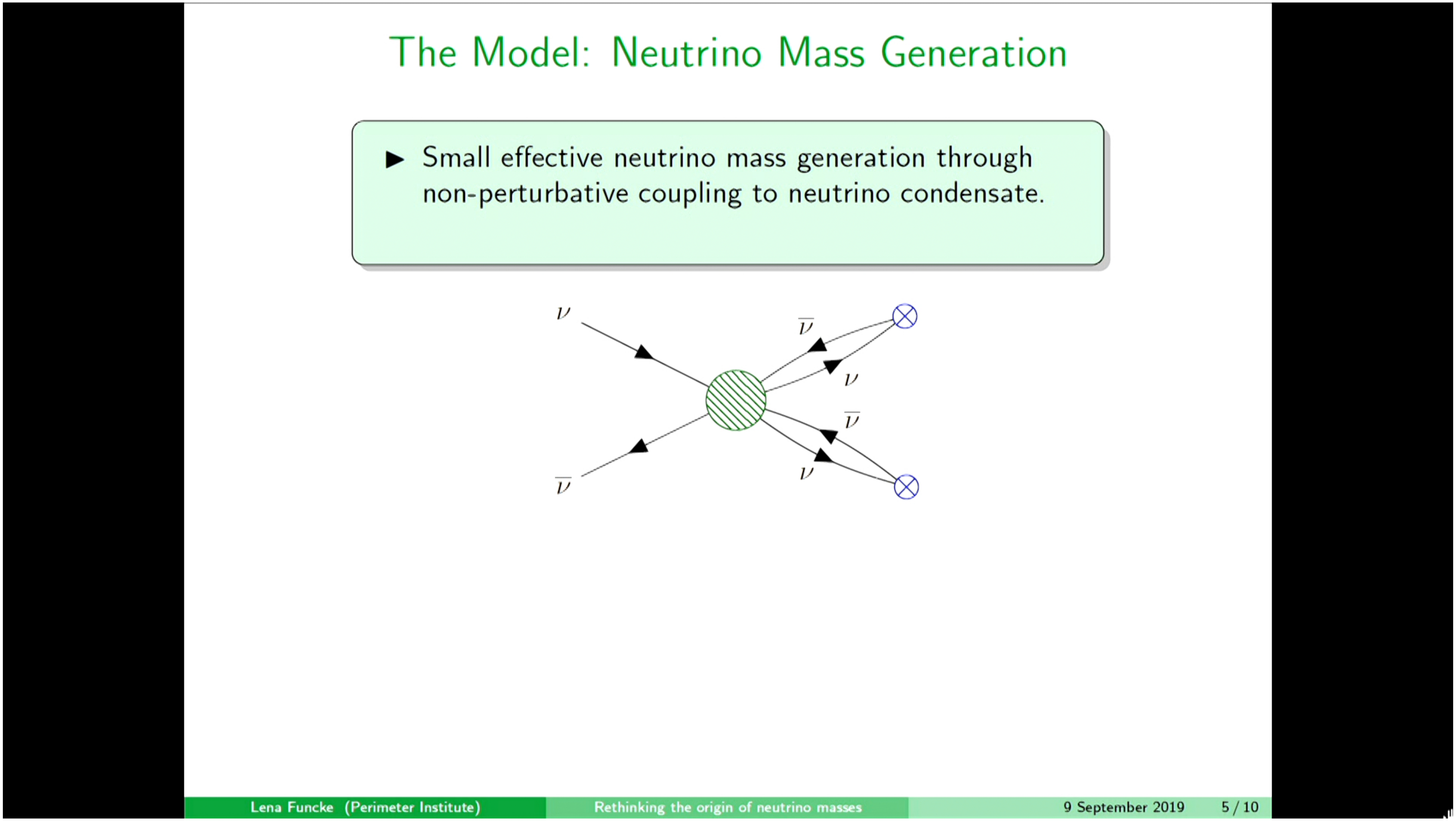
Neutrino flavor symmetry breaking through chiral gravitational anomaly.



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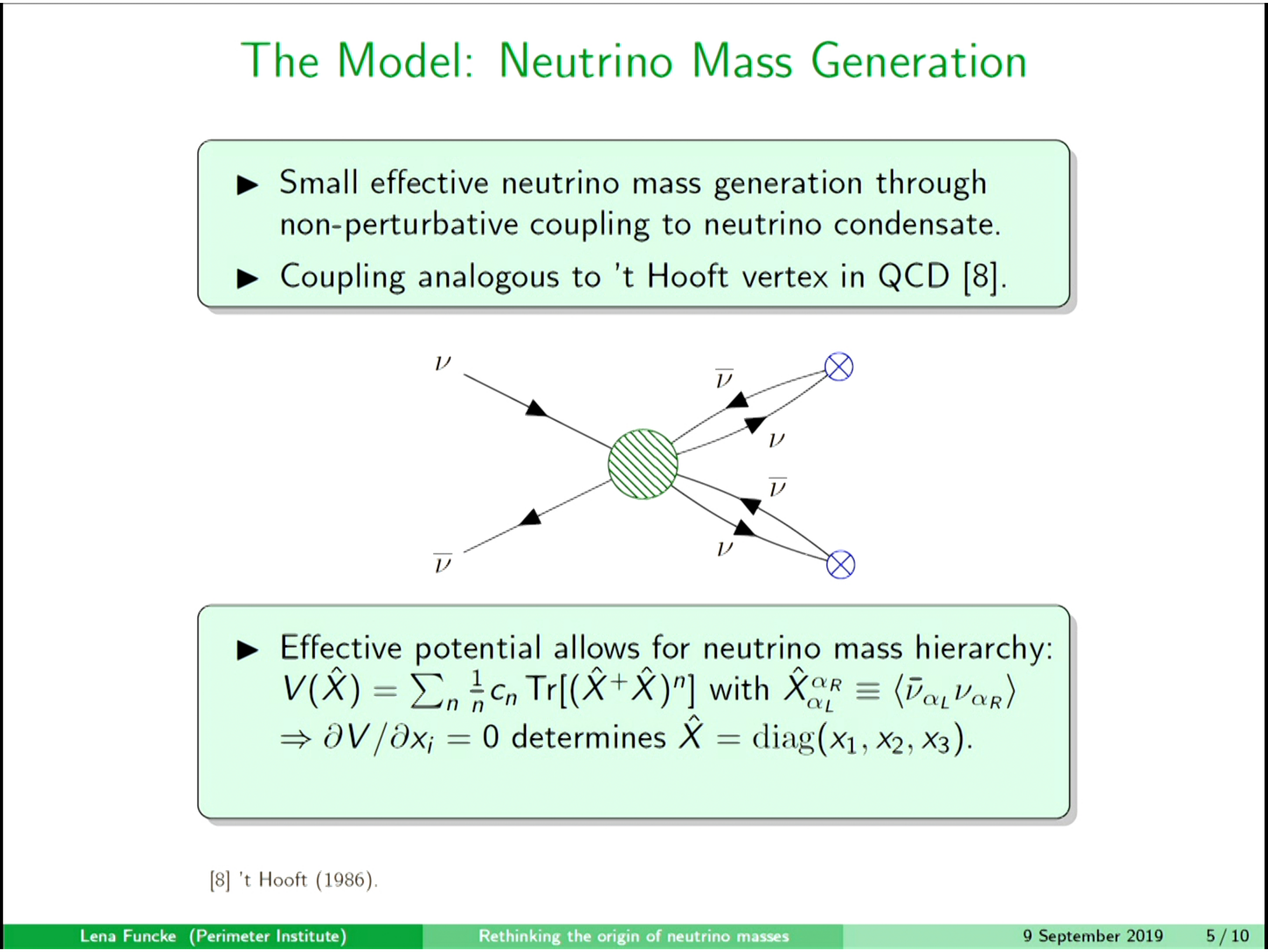

The Model: Neutrino Mass Generation

- Small effective neutrino mass generation through non-perturbative coupling to neutrino condensate.
- Coupling analogous to 't Hooft vertex in QCD [8].

- Effective potential allows for neutrino mass hierarchy: $V(\hat{X}) = \sum_n \frac{1}{n} c_n \mathrm{Tr}[(\hat{X}^+\hat{X})^n]$ with $\hat{X}^{\alpha_R}_{\alpha_L} \equiv \langle \bar{\nu}_{\alpha_L} \nu_{\alpha_R} \rangle$ $\Rightarrow \partial V / \partial x_i = 0$ determines $\hat{X} = \mathrm{diag}(x_1, x_2, x_3)$.

[8] 't Hooft (1986).

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Assumption: condensate $|\langle\bar{\nu}\nu\rangle| =$ scale $\Lambda_G^3 =$ temperature $T_{\chi\mathrm{SB}}^3$.

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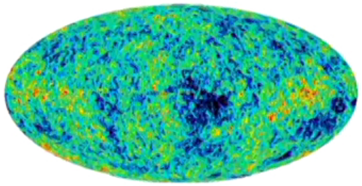
$\Lambda_G \ll m_e$

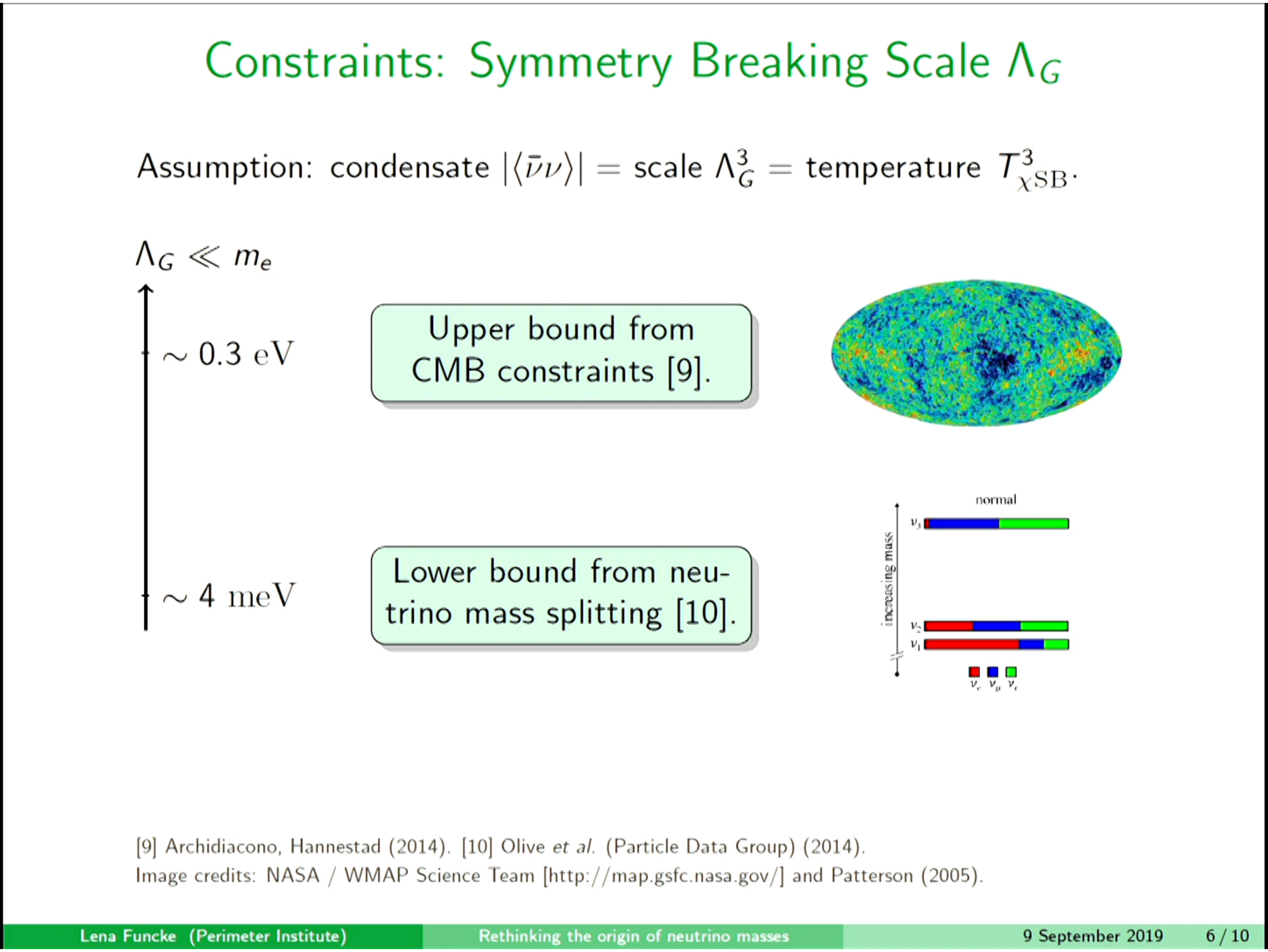
$\sim 0.3\ \mathrm{eV}$

Upper bound from CMB constraints [9].



[9] Archidiacono, Hannestad (2014).

Image credits: NASA / WMAP Science Team [http://map.gsfc.nasa.gov/]



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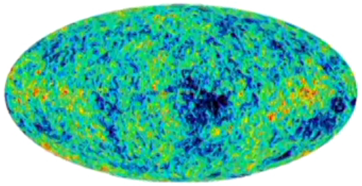

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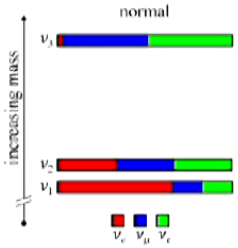

→ Neutrino vacuum condensate $\langle\bar{\nu}\nu\rangle$ on dark energy scale.

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Phenomenological Implications

Weakened cosmological neutrino mass bounds.

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- Neutrinos decay & (partially) annihilate $\rightarrow \sum_i m_{\nu_i} \not\lesssim 0.12$ eV [11].

$\Rightarrow$ Masses $m_{\nu_e} \lesssim 2.2$ eV [12] still allowed, measurable at KATRIN.

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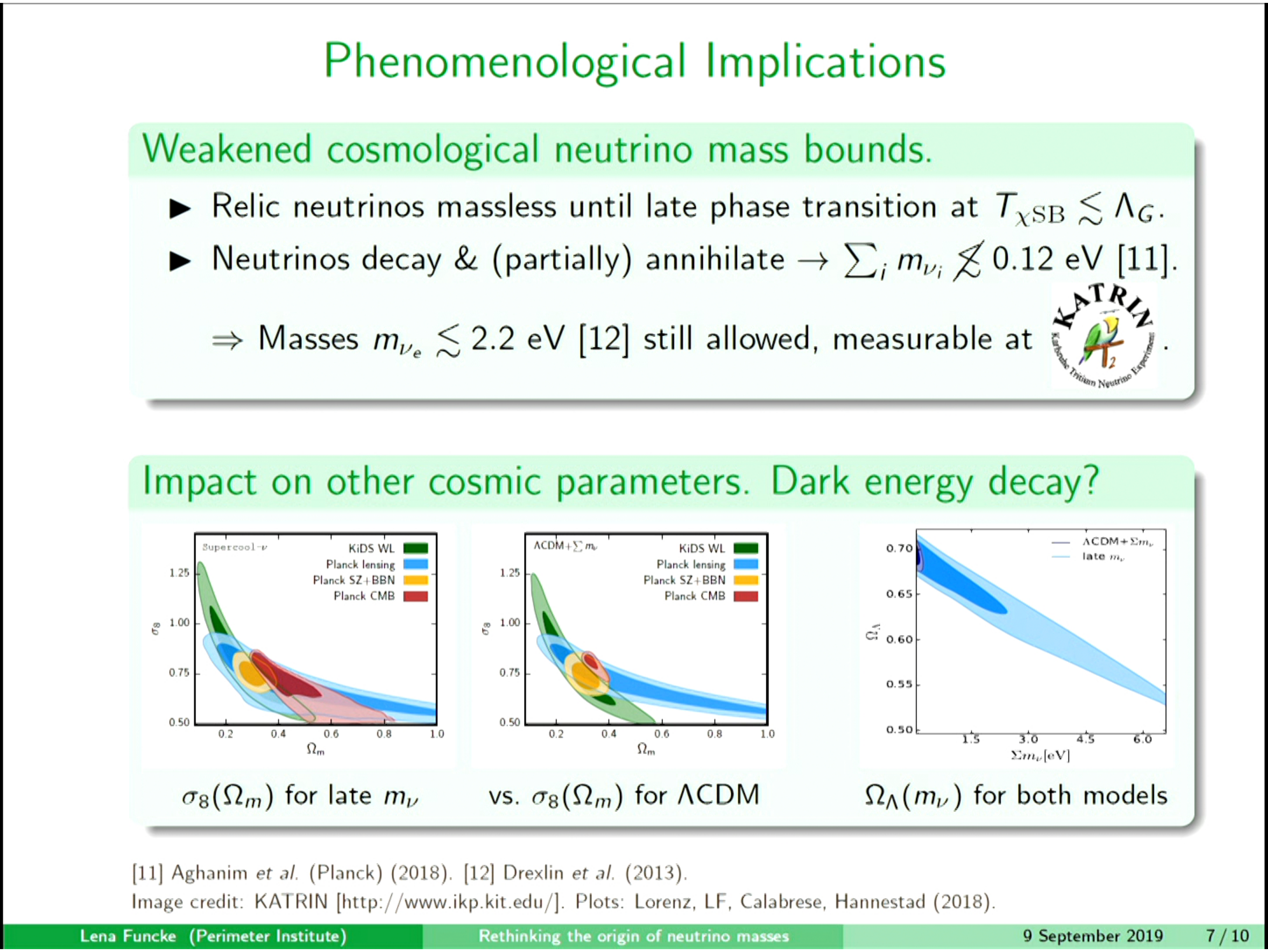
Image credit: KATRIN [http://www.ikp.kit.edu/].



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Impact on other cosmic parameters. Dark energy decay?

$\sigma_8(\Omega_m)$ for late m_ν vs. $\sigma_8(\Omega_m)$ for ΛCDM $\Omega_\Lambda(m_\nu)$ for both models

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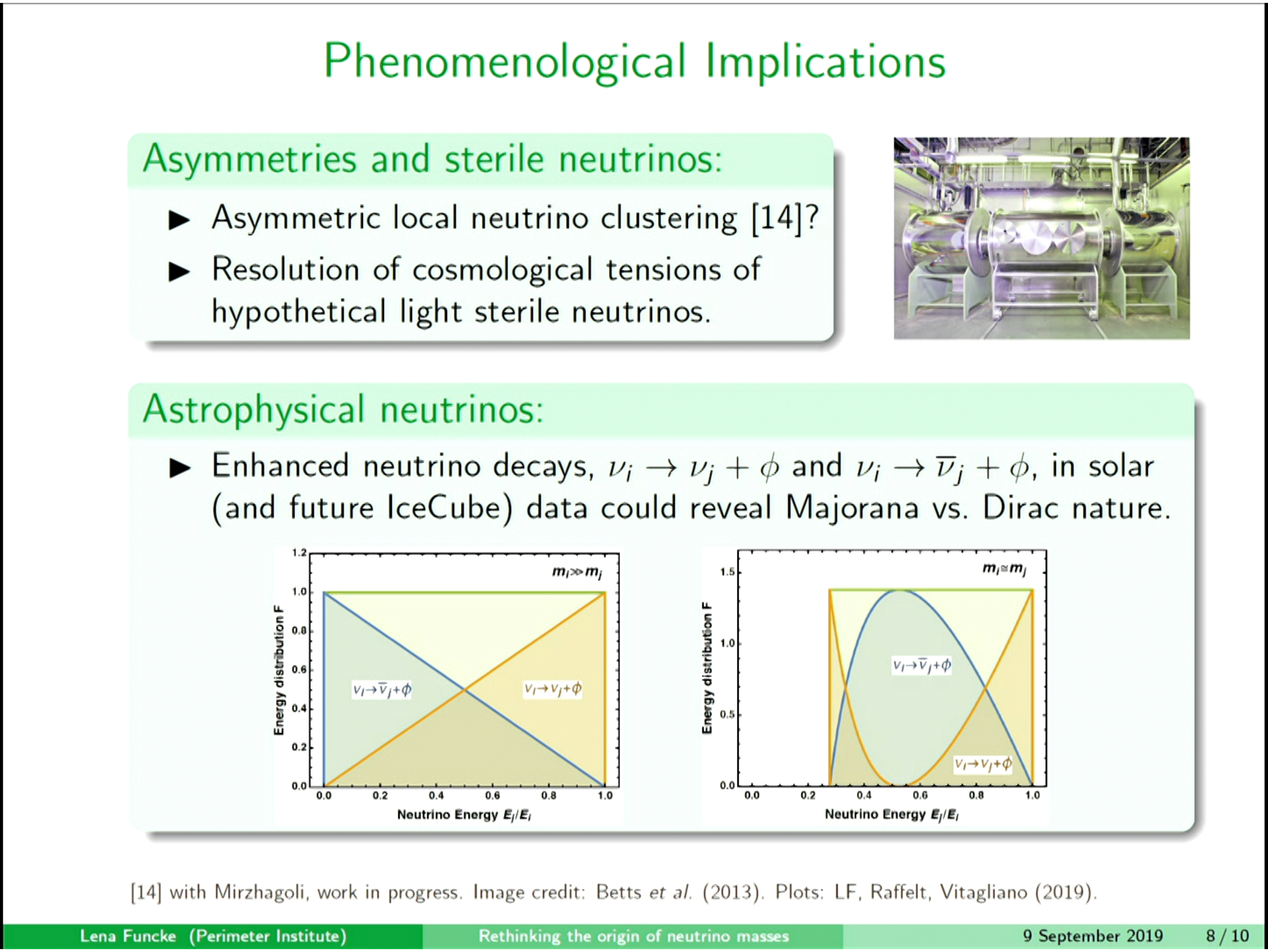
Image credit: KATRIN [http://www.ikp.kit.edu/]. Plots: Lorenz, LF, Calabrese, Hannestad (2018).



Phenomenological Implications

Asymmetries and sterile neutrinos:

- Asymmetric local neutrino clustering [14]?
- Resolution of cosmological tensions of hypothetical light sterile neutrinos.

Astrophysical neutrinos:

- Enhanced neutrino decays, $\nu_i \to \nu_j + \phi$ and $\nu_i \to \overline{\nu}_j + \phi$, in solar (and future IceCube) data could reveal Majorana vs. Dirac nature.

[14] with Mirzhagoli, work in progress. Image credit: Betts *et al.* (2013). Plots: LF, Raffelt, Vitagliano (2019).

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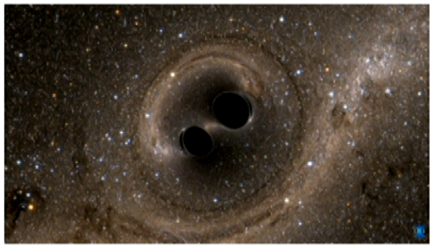
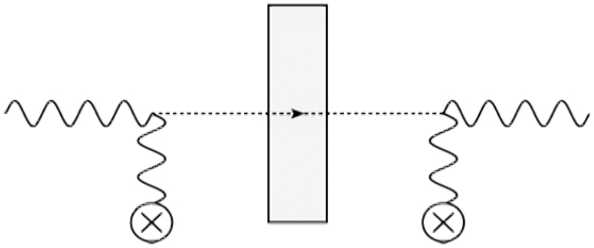
Gravity measurements:

- Different polarization intensities of gravitational waves [16].
- New attractive gravity-competing short-distance force [17].





New particle detection:

- "Shining light through walls" with axion-like bosons η_ν, ϕ_k.
- Possible deep-infrared origin of flavor-violating processes.

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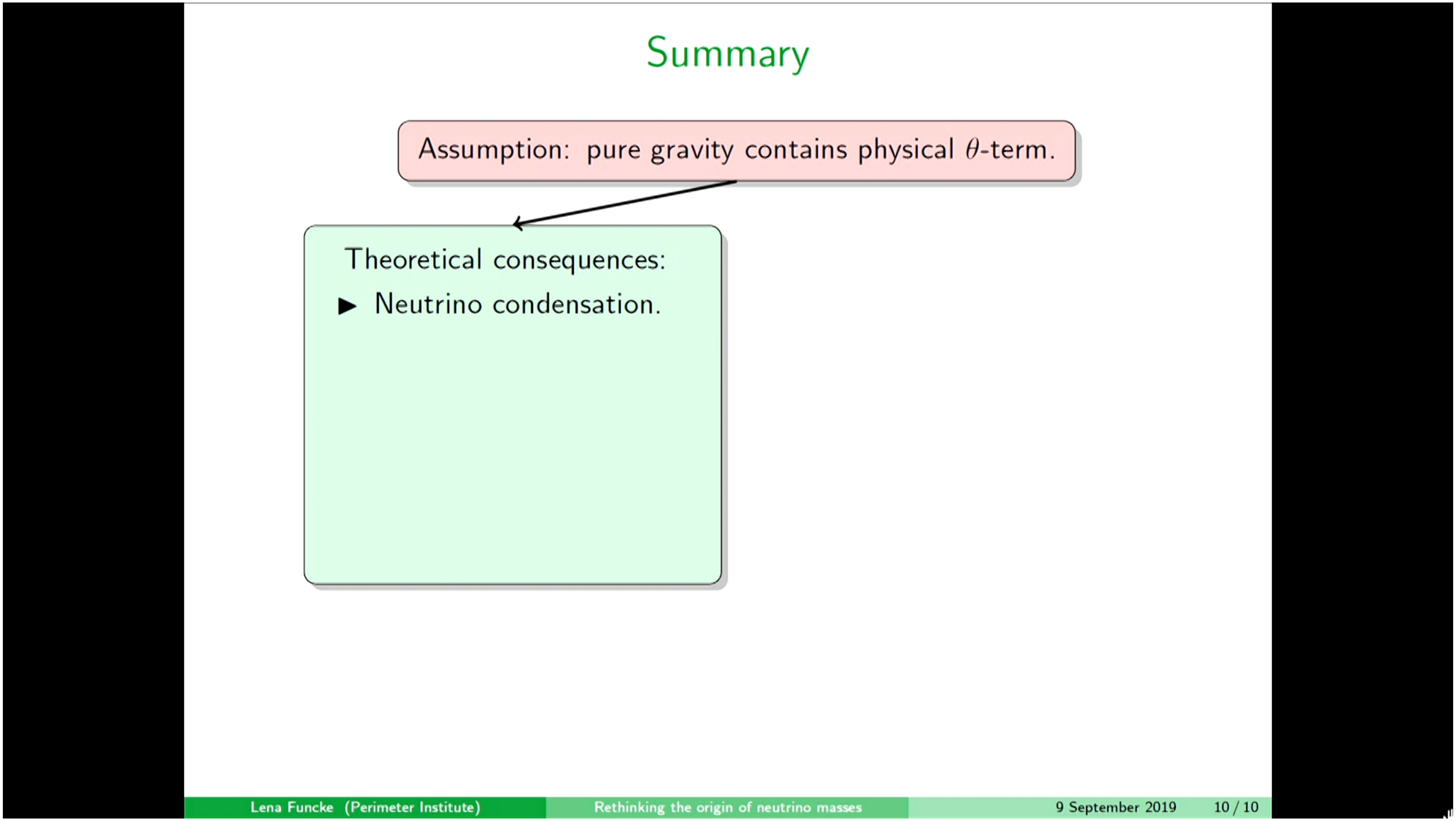
Image credits: The SXS Project [https://www.ligo.caltech.edu/] and Redondo, Ringwald (2010).



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- Works for both Dirac and Majorana neutrinos.

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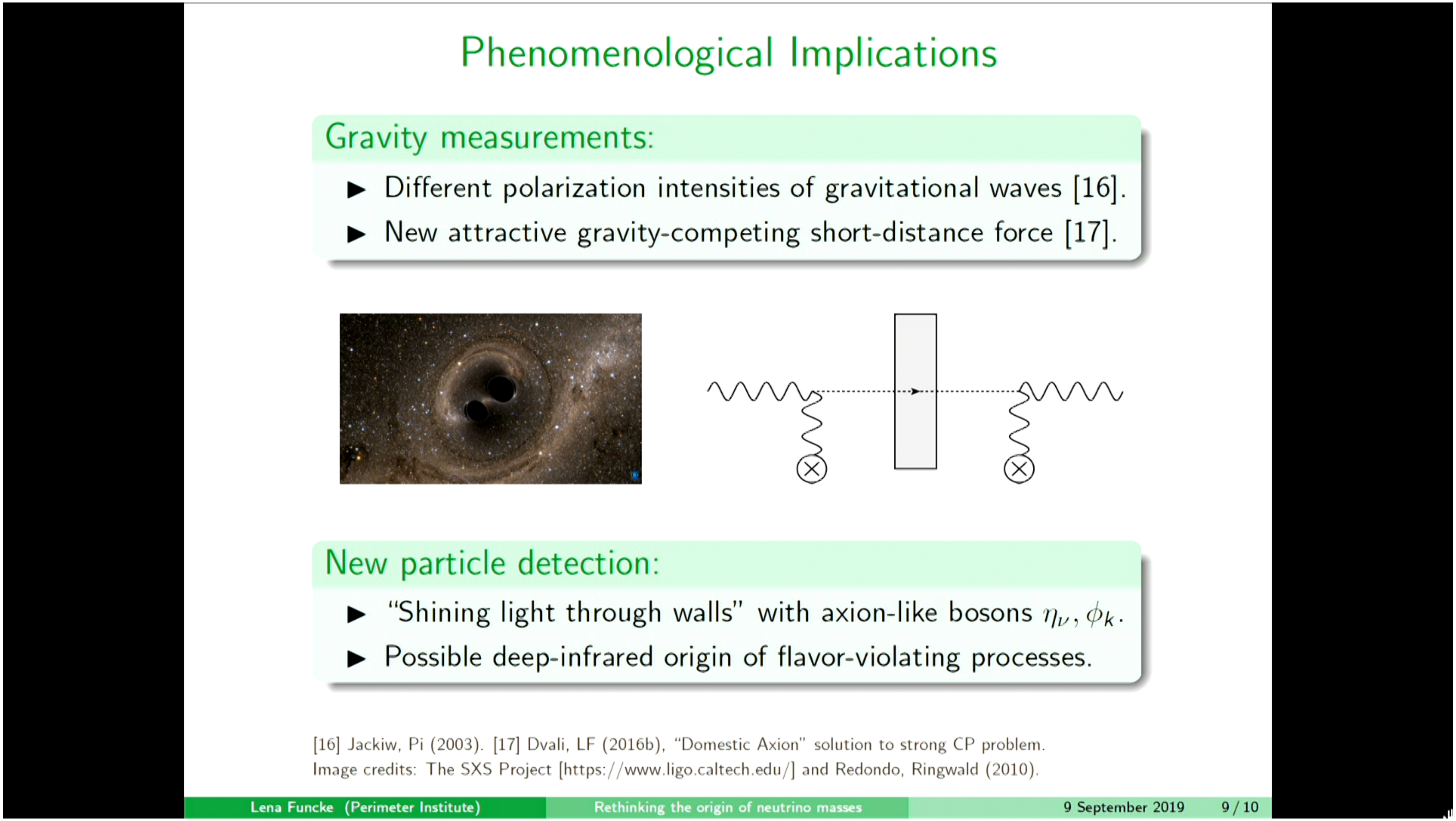
- Large neutrino masses still cosmologically allowed.
- Enhanced neutrino decays.
- Possible signatures at KATRIN, IceCube, etc.
- More details on arXiv: 1811.01991 & 1905.01264



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Do you have any questions?